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STABILITY AND DECAY OF FREE VORTICES BEHIND A WING

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Hans Bippes **

ABSTRACT. A counterrotating vortex pair with axes leaves the ends of a finite wing in the flow direction. The intensity of this system of free vortices increases with the specific span load of the wings. In modern aircraft it can become so large that the safety of following aircraft is endangered. Investigations of the vortex train regarding the intensity decrease in time and the decay of these vortices is especially important because of the increase in traffic at airports. /455*

A water towing channel was used for the experimental investigation of the free vortex system. In this test installation, the flow medium is at rest and the model is moved. This arrangement makes it possible to observe the vortices up to their decay for over a minute. This time corresponds to a distance from the producing wing of over 60 m, depending on the selected towing velocity.

The model used (Figure 1) in most experiments was the rectangular wing with a 8% Clark Y profile and a span of 0.16 m. In order to isolate the free vortices from the wake disturbances of the model support, for example of a "sting", it is suspended only by 0.1 mm wires having a high strength between four rigid profile bars, which emerged from the towing vehicle into the water. This is shown in Figure 1 as well.

* Numbers in the margin indicate pagination of original foreign text.

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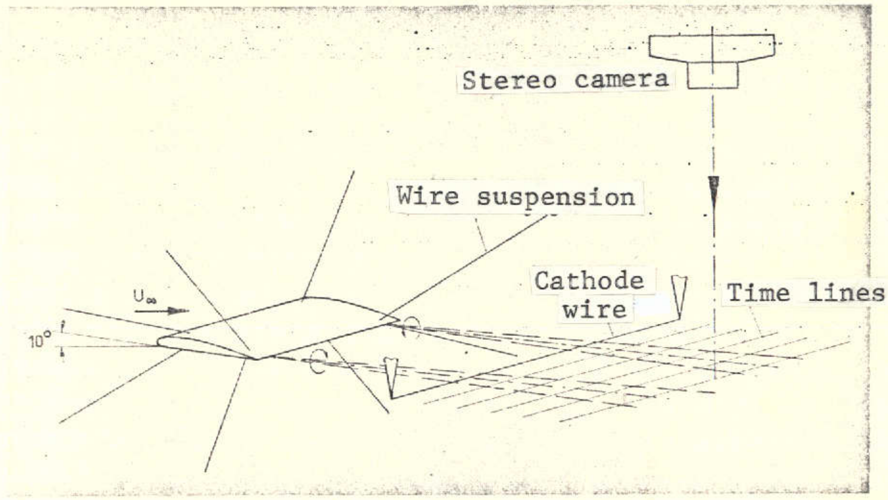

Figure 1. Test arrangement

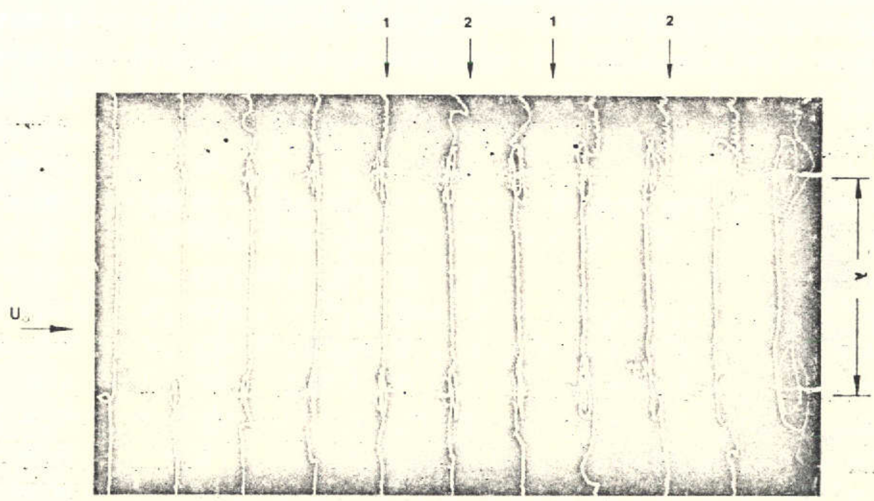

Figure 2. Deformation of hydrogen small bubble time lines corresponding to the velocity distribution in the vortices, 20 spans (3.2 m) behind the wing or 8 sec. after they are produced with periodically occurring minima (1) and maxima (2) in the axial velocity component. λ = axial distance between free vortices

The results are found by making the flow visible using the hydrogen bubble method. The cathode wire at which the hydrogen is produced by electrolysis of the water is suspended between the tips of a fork-shaped probe carrier. In the experiments to be discussed below, it was always parallel to the trailing edge of the wing.

The direction of the stereo camera was perpendicular to the plane of the vortex axes. The hydrogen bubbles were produced either periodically (Figures 2 and 3) or continuously (Figures 3 and 4).

Figure 2 shows a qualitative impression of the velocity distribution in the free vortices 20 spans (3.2 m) behind the wing or 8 sec. after they were produced. The size of the circulation can be seen by the number of windings of the time lines around the vortex axis. In the vicinity of the vortex center, in the so-called vortex core, there is also an axial velocity component directed towards the wing, which pulls apart the windings of the time lines to form spirals. The radial velocity component is very small compared with the other two components and is directed towards the vortex center.

The decay of the vortices is introduced by various insta- /456 bilities inside and outside of the core. Inside of the vortex core, there are fluctuations of the axial velocity which are periodic in time. In Figure 2 (upper vortex) one can observe the spiral parts of the time lines in the vortex axes by the periodic decrease and increase in the distances between the tips.

Later on, turbulent "spots" (Figure 3) are formed from these fluctuations, which finally make the flow turbulent in the core. The diameter of the core in this process increases rapidly.

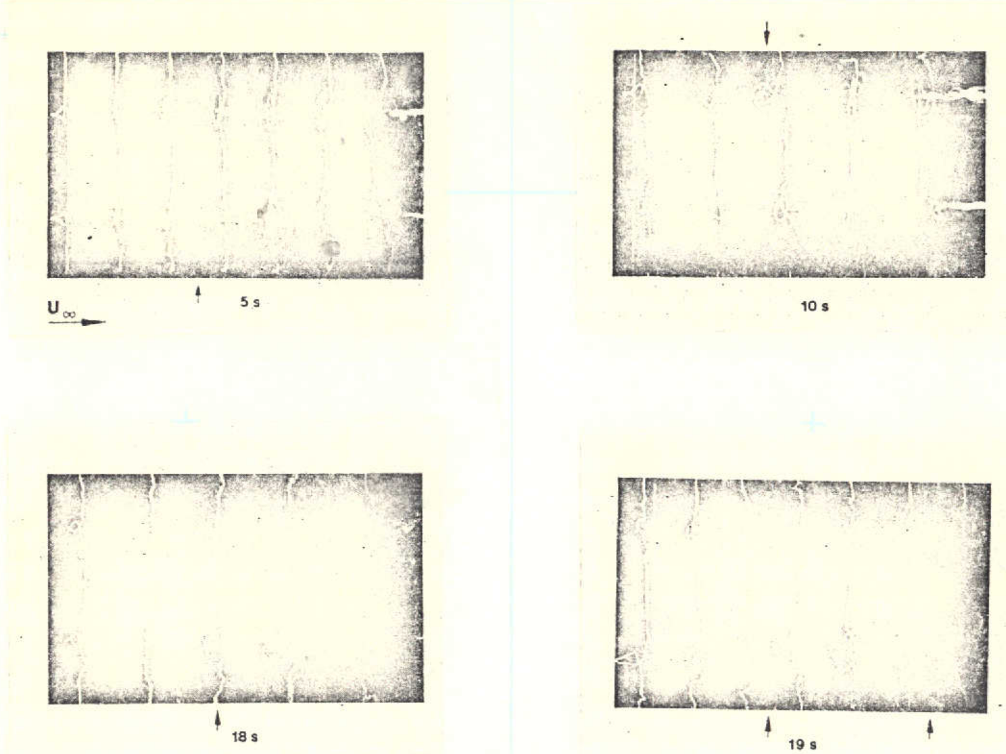

Figure 3. Development of turbulence in the vortex core, 5, 10, 18 and 19 sec. after vortex production. (↑) local development of turbulence ("turbulent spot")

Outside of the core we find the instabilities shown in Figure 4. The hydrogen bubbles were continuously produced for this photograph. This is why the cathode wire parallel to the trailing edge of the wing is sometimes above the vortex (upper left) and sometimes below the vortex core (lower right figure). In both cases the instabilities become visible when the cross sections are observed.

These are again vortex pairs with counterrotating direction. /457
This can be observed on the outer (Figure 4 lower right) as well as in the inner edge (Figure 4 top left) of the free vortices. Therefore it can be concluded that the vortex pairs enclose the cores of the free vortices in the form of rings or spirals with a very small inclination. This becomes especially clear when stereo pictures are observed. This means that this instability represents

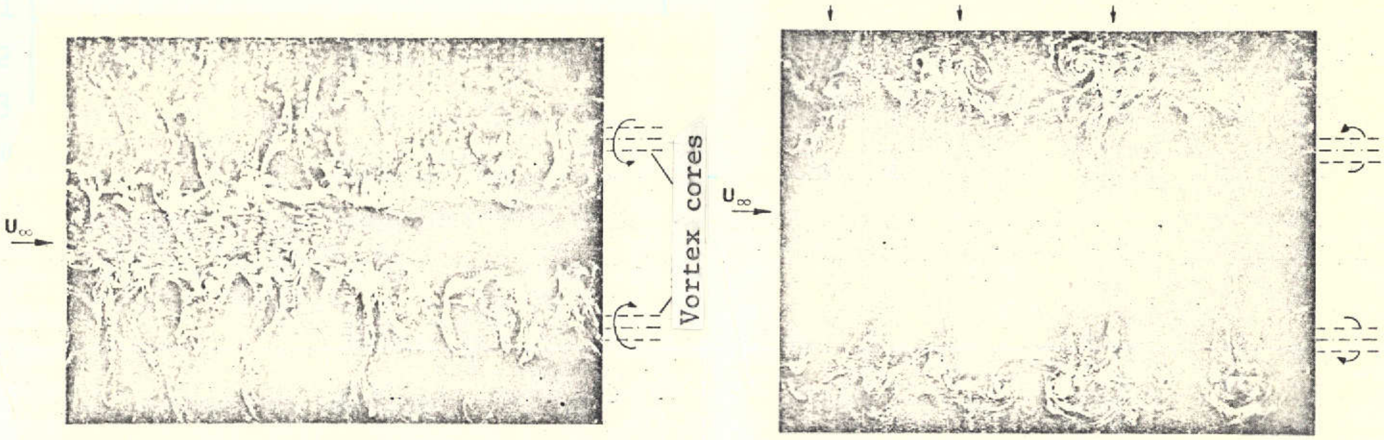

Figure 4. (left): Instabilities in the shape of counterrotating vortex pairs, which surround the core of the free vortices (↓)

Top figure (left): Bubble formation above the vortex core. The instabilities inside the free vortices are visible in the cross section

Figure (right): Bubble production below the vortex core. All the instabilities outside of the free vortices are visible in the cross section

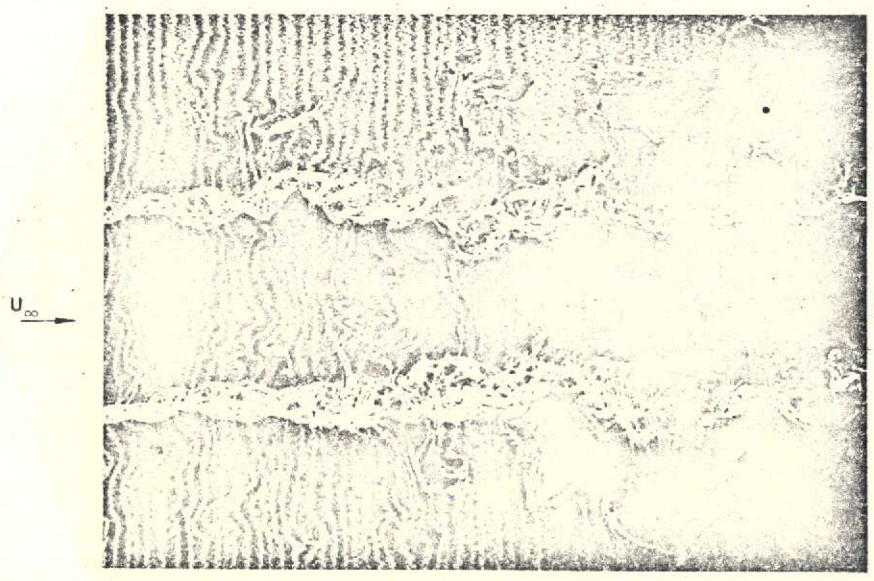

Figure 5. The free vortices just before their decay, with snake-like turbulent vortex cores and turbulent external flow

counterrotating, torus-shaped or spiral vortex pairs with a small inclination. Later on the number of these vortex disturbances increases because more and more new vortex pairs having different wave lengths are formed, which are also displaced in the radial direction with respect to each other. At the same time, the difference in the wave length of the individual vortex pairs continues to increase and therefore the perturbation motion becomes more and more disorganized, until transition to turbulence occurs.

As soon as the vortex flow inside and outside of the core has become turbulent, the circulation is decomposed at an accelerated rate. The decay process is intensified if there is also a snake-like motion of the vortex streaks, as shown in Figure 5. This snake motion of the free vortices, which can be observed in the condensation strips of aircraft at high altitudes, can also be looked upon as a further characteristic instability. It can also be observed in a similar form for other counterrotating vortex systems, for example, behind individual roughness elements, in the unstable gap flow of the Taylor cylinder and in the unstable boundary layers of concave and heated walls. These are flows which have been investigated at the Institute for Applied Mathematics and Mechanics of the DFVLR in Freiburg for a long time, using theoretical and experimental methods. The similarity of these instabilities with the instabilities of the free vortices was the reason for our investigations.

The decay of the free vortices, which depart from the wing tips, takes over one minute for the experiments carried out here at Reynolds numbers of $Re = 10^4$ to $Re = 10^5$. Larger Reynolds numbers and larger specific span loads of the wings can increase with time. Therefore, it must be considered in the planning of permissible takeoff and landing sequences at airports.

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16. Abstract

An experimental investigation was conducted regarding the system of free vortices which detach themselves from a rectangular wing. During the tests the model was moved while the fluid medium remained at rest. This approach made it possible to observe the vortices for more than one minute until they finally decayed. The flow was made visible with the aid of hydrogen bubbles which were obtained by electrolysis of the medium water by means of a wire serving as cathode.

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